Improved spectral and angular characterization of Libya-4 and Dome-C for consistent MODIS and VIIRS radiometric scaling

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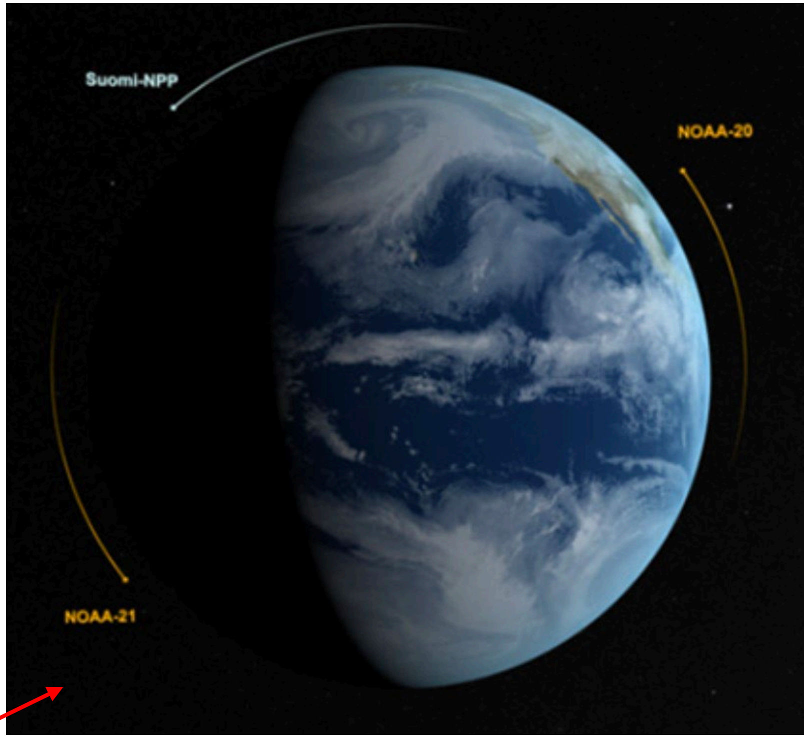
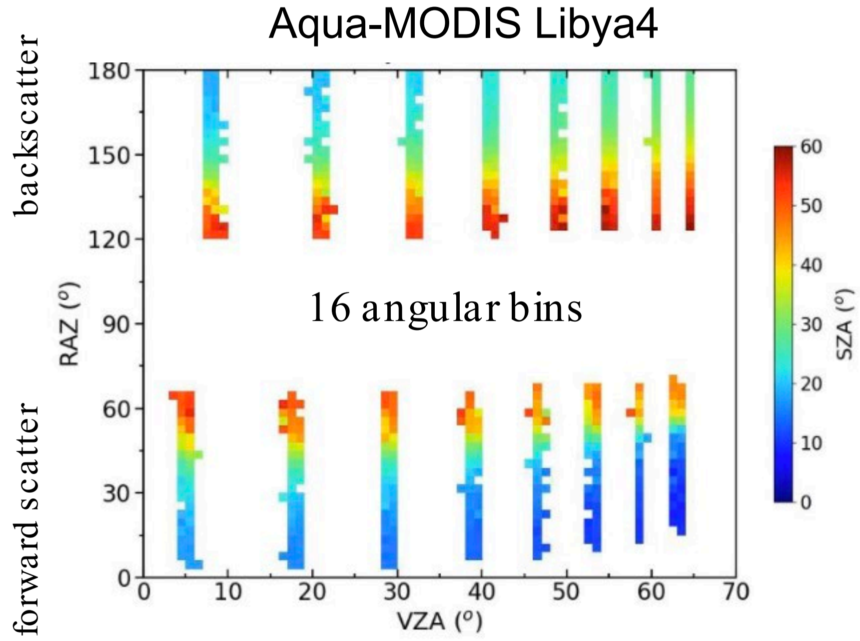
Introduction

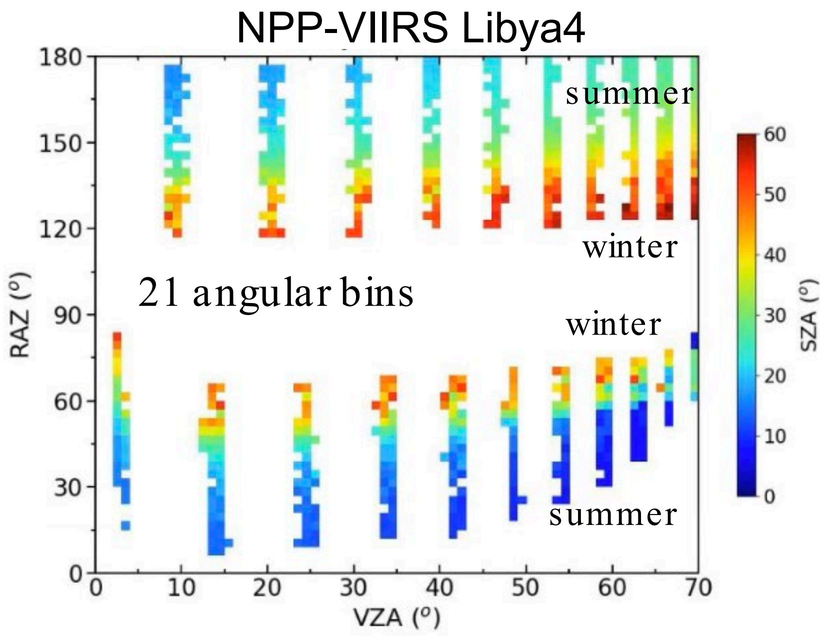
- The NASA CERES project radiometrically scales the Terra-MODIS, NPP-VIIRS, NOAA20-VIIRS, and Geostationary imagers RSB to the Aqua C6.1 reference to facilitate consistent flux and cloud retrievals
- CERES utilizes ray-matched coincident sensor radiance pairs to obtain radiometric scaling factors
- Outside of the poles, no direct comparisons between Aqua, SNPP and NOAA20 VIIRS are now possible
  - The Terra and Aqua satellites are slowly drifting towards the terminator and will be deorbited in 2026
  - This will prevent any direct comparisons of SNPP and NOAA20 with Aqua.
  - No direct comparisons between SNPP and NOAA20 VIIRS are possible, since they are located a half an orbit apart.
- Characterize Libya-4 and Dome-C PICS to monitor sensor stability and obtain radiometric scaling factors



Angular binning

- The Terra, Aqua, NPP and NOAA-20 have a 16-day repeat cycle, where the ground track is replicated 16 days later.
- The Libya-4 MODIS observations are stratified into 16 VZA and relative azimuth angular bins
- The Libya-4 VIIRS observations are stratified into 21 VZA and relative azimuth angular bins, because the oblique orbital swaths overlap





NPP and N20 angular bins are identical

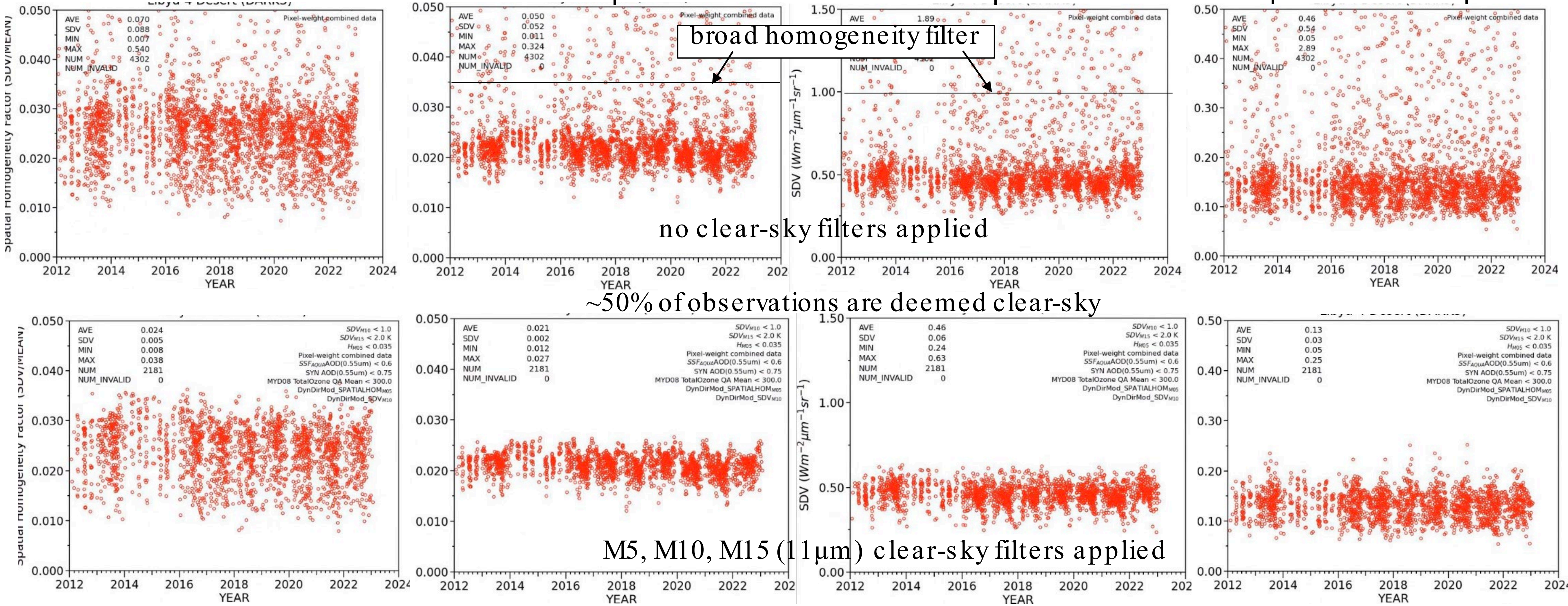
Libya-4 NPP-VIIRS clear-sky identification

M3 (0.49 µm) impacted by AOD and Rayleigh Scattering

M5 (0.67 µm) not impacted

M10 (1.61 µm) not impacted

M11 (2.25 µm) impacted water vapor



For each angular apply M5 and M10 2σ filter twice to remove outliers to preserve clear-sky WV, O3 and AOD variability

BRDF and Atmospheric Correction

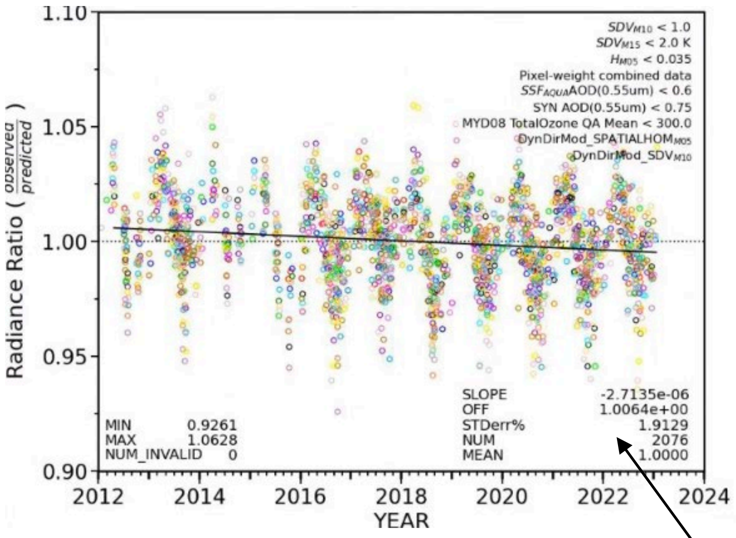
- For each angular bin and spectral channel, the BRDF is characterized by regressing the clear-sky daily observations over the record as follows
  - $Rad_{pred} = g_0 + g_1*\cos(SZA) + g_2*\cos(SZA)^2$
- The atmospheric correction are linear coefficients based on the daily PW, ozone concentration, and AOD retrievals over the PICS
  - $Rad_{pred} = a_0 + a_1*\cos(SZA) + a_2*\cos(SZA)^2 + a_3*PW + a_4*O3 + a_5*AOD$
- The normalized radiance is computed as follows
  - $rad_{norm} = rad_{obs}/rad_{pred}$
- The trend standard error (Trend-SE) is the linear trend standard error of the daily normalized radiances over the sensor record

Atmospheric datasets

- PW
  - PW-MERRA is based on the assimilation of Aqua-Atmospheric Infrared Sounder (AIRS) and the Advanced Microwave Sounding Unit-A (AMSU-A) observations as well as soundings from ground-based observations.
  - PW-RSB (MYD08-D3) approach compares the 0.905, 0.936, and 0.94 μm water vapor absorbing channels with the 0.865 and 1.24 μm atmospheric window channels (NIR retrieval approach)
  - PW-IR (MYD08-D3) approach mainly compares the 6.72 μm and 7.33 μm water vapor channels to the 8.55μm window channel (IR retrieval approach)
- Ozone
  - O3-MERRA is derived from SNPP- Ozone Mapping and Profiler Suite (OMPS) and NOAA20-OMPS and Aura-Ozone Monitoring Instrument (OMI) UV observations
  - O3-MYD08 is mainly retrieved from the MODIS 9.6 μm channel
- Aerosols – Libya-4 only
  - AOD-MYD08 MODIS deep blue aerosol retrieval during clear=-sky
  - AOD-MATCH Multi-scale Atmospheric Transport and Chemistry (MATCH) is a Eulerian three-dimensional model where MODIS AOD retrievals are assimilated in 3-hourly chunks. The desert dust-sizes are determined by wind speed.

Libya-4 atmospheric correction based on PW dataset

SNPP-VIIRS, M11 (2.1μm), Without PW



SNPP-VIIRS, M11, With PW-RSB

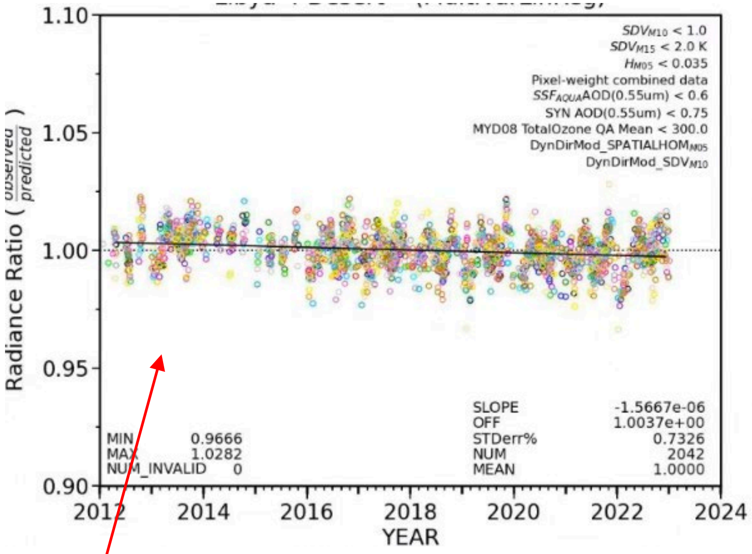
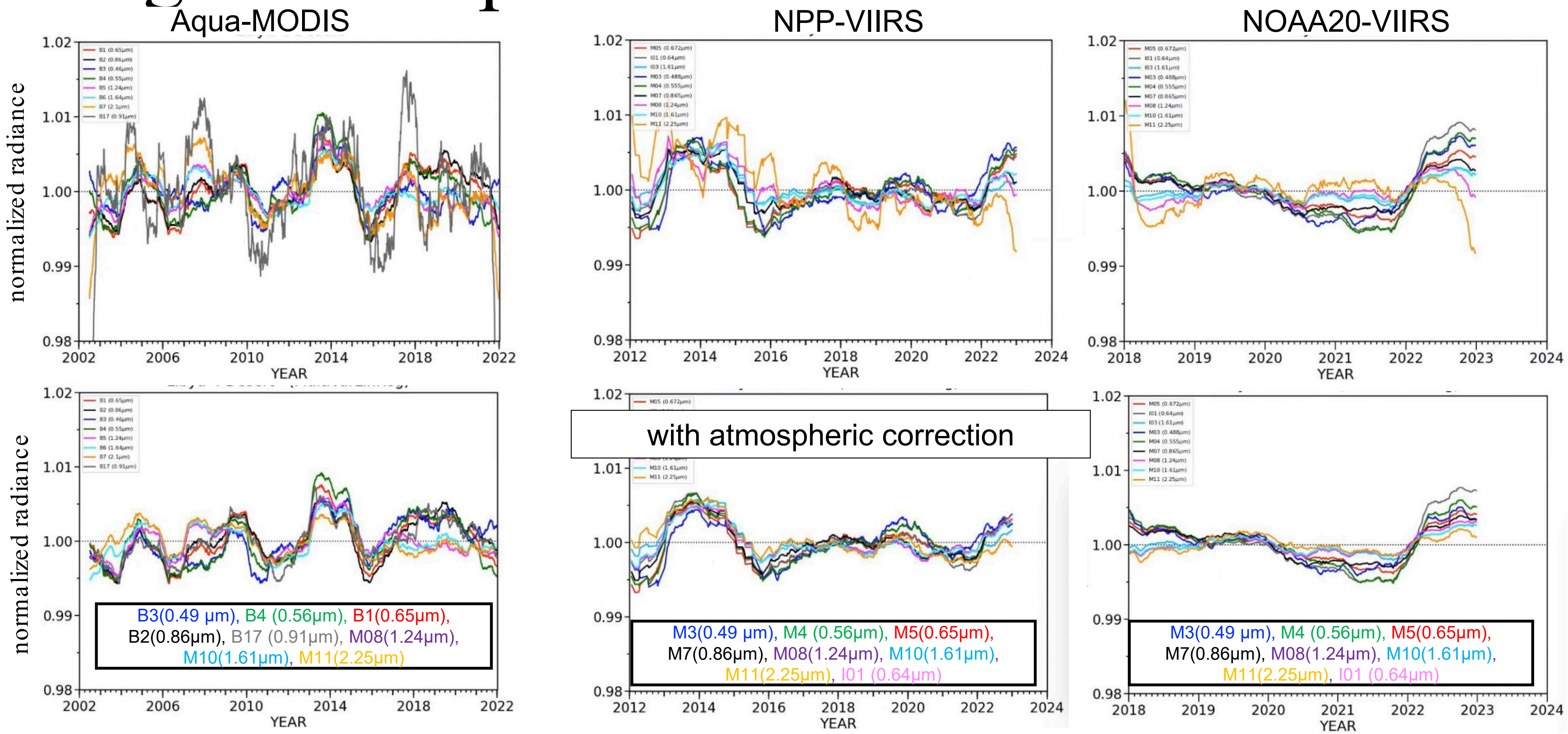


Table of the trend-SE

NPP	M3	M4	M5	M7	M8	M10	M11	I01	I03
Channel				WV	WV		WV		
Cos(SZA)	1.102	0.885	0.686	0.745	1.051	0.636	1.923	0.801	0.636
PW-RSB	1.054	0.876	0.682	0.630	0.627	0.592	0.733	0.765	0.593
PW-IR	1.065	0.878	0.682	0.652	0.742	0.595	1.217	0.773	0.596
PW- MERRA	1.052	0.871	0.682	0.658	0.722	0.607	1.022	0.775	0.608

The PW-RSB is the most effective PW dataset to reduce the water vapor absorption band trend-SE

The Libya-4 natural variability is similar across imagers and spectral bands



365 running day means

Libya-4 atmospheric corrected trend-standard error spectral consistency

band not impacted by atmosphere

SAT/ BANDS	Libya4	0.64 (B1)	0.87 (B2)	0.46 (B3)	0.55 (B4)	1.24 (B5)	1.629 (B6)	2.10 (B7)	0.91 (B17)	
			PW	AOD	O3	PW		PW	PW	
Aqua	Cos(SZA)	0.896	0.959	1.201	0.971	0.868	0.620	2.028	5.846	
	With atmosphere	0.774	0.699	0.959	0.861	0.626	0.579	0.662	1.200	
	□Δ (%)	14	27	20	11	28	7	67	79	
Terra	Cos(SZA)	0.972	1.064	1.532	1.047	1.015	0.707	2.251	5.695	
	With atmosphere	0.766	0.670	1.321	0.940	0.801	0.640	1.079	1.171	
	□Δ (%)	21	37	14	10	21	9	52	79	
	2002-2008	0.721	0.618	0.900	0.770	0.645	0.536	0.595	1.014	
SAT/ BANDS		0.67 (M5)	0.87 (M7)	0.49 (M3)	0.55 (M4)	1.24 (M8)	1.629 (M10)	2.10 (M11)	0.64 (I1)	1.61 (I3)
			PW	AOD	O3	PW		PW		
N20	Cos(SZA)	0.725	0.713	1.101	0.939	1.072	0.665	1.983	0.884	0.673
	With atmosphere	0.659	0.629	1.013	0.838	0.643	0.602	0.758	0.765	0.605
	□Δ (%)	9	12	8	11	40	9	62	13	10
NPP	Cos(SZA)	0.686	0.748	1.100	0.885	1.051	0.636	1.923	0.801	0.636
	With atmosphere	0.652	0.618	0.986	0.808	0.615	0.560	0.714	0.696	0.581
	□Δ (%)	5	17	10	9	41	12	63	13	9

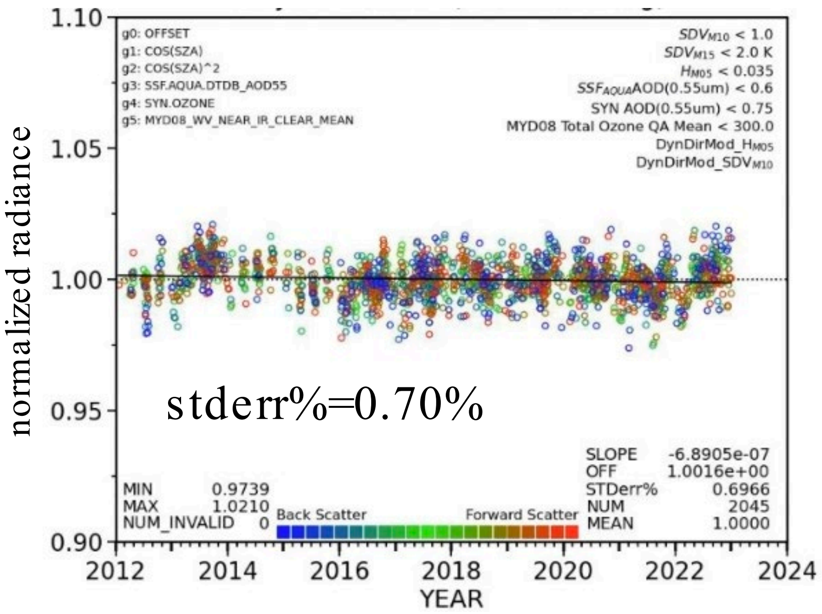
- PW was the most effective atmospheric correction, up to 60% for the 2.2µm channel

Comparison of the NPP-VIIRS observations normalized with the NPP or N20 BRDFs

- To radiometrically scale NPP to the N20-VIIRS calibration reference, then apply the N20-VIIRS BRDF to the NPP-VIIRS observations

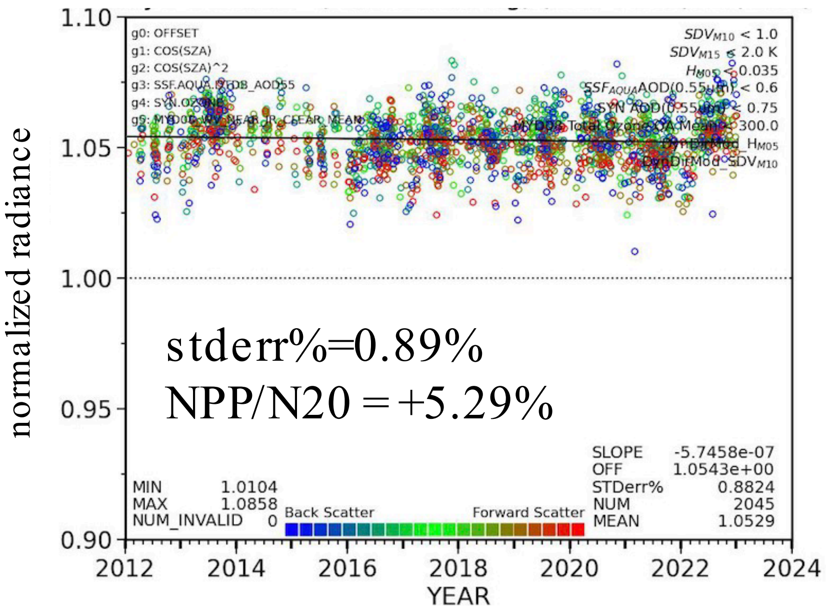
NPP-VIIRS observations normalized with the NPP $BRDF_{atm}$

NPP-VIIRS, I1 (0.65µm) (NPP $BRDF_{atm}$)



NPP-VIIRS observations normalized with the N20 $BRDF_{atm}$

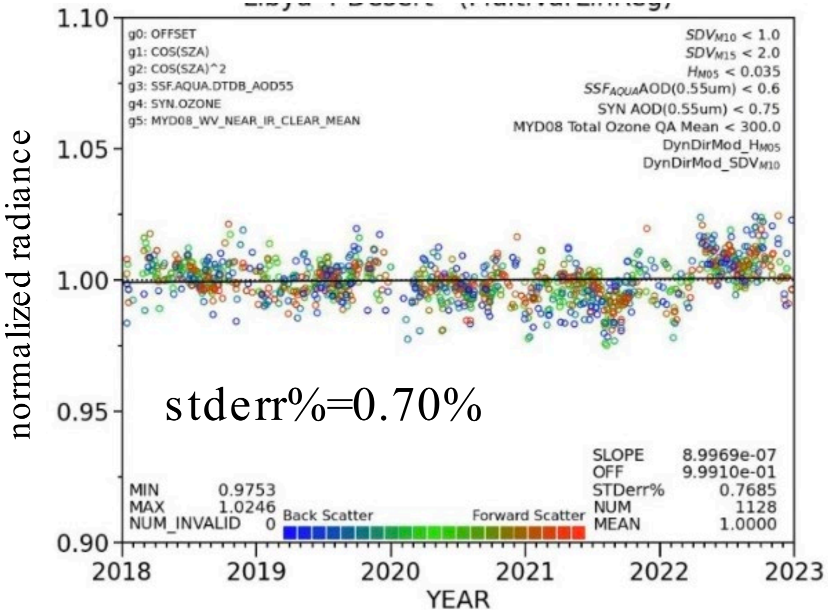
NPP-VIIRS, I1 (0.65µm) (N20 $BRDF_{atm}$)



Comparison of the N20-VIIRS observations normalized with the NPP or N20 BRDFs

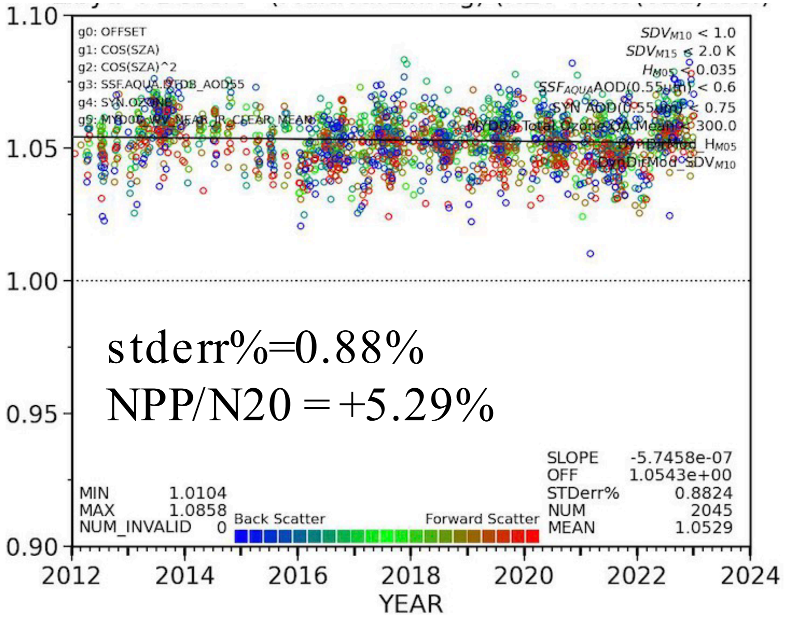
N20-VIIRS observations normalized with the N20 $BRDF_{atm}$

N20 , I1 (0.65μm) (N20 $BRDF_{atm}$)



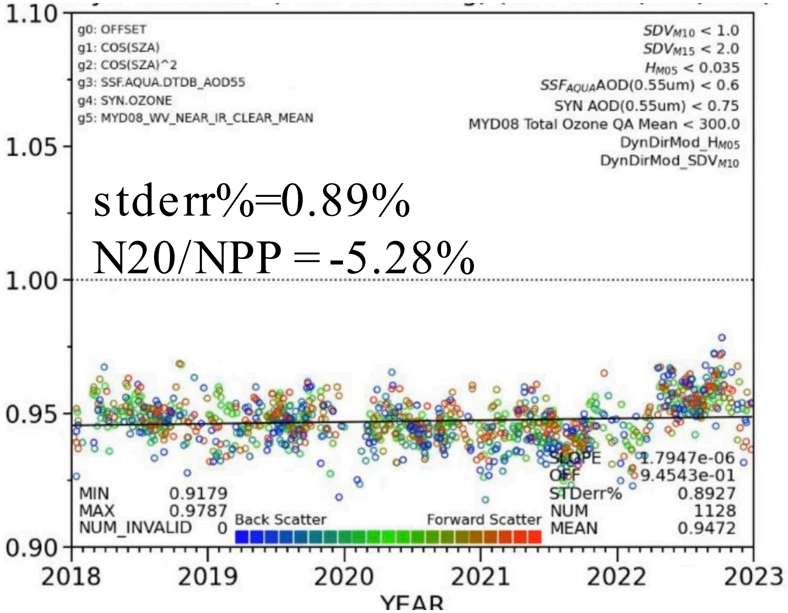
NPP-VIIRS observations normalized with the N20 $BRDF_{atm}$

NPP , I1 (0.65μm) (N20 $BRDF_{atm}$)



N20-VIIRS observations normalized with the NPP $BRDF_{atm}$

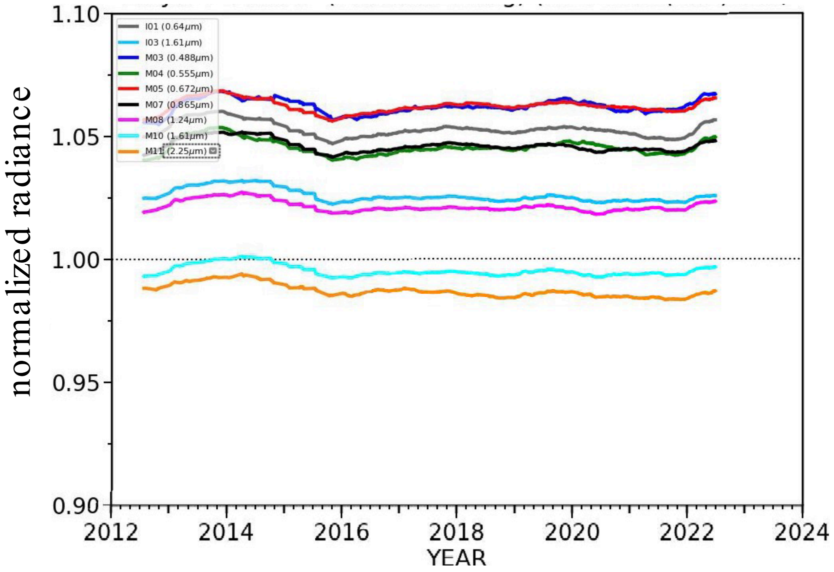
N20 , I1 (0.65μm) (NPP $BRDF_{atm}$)



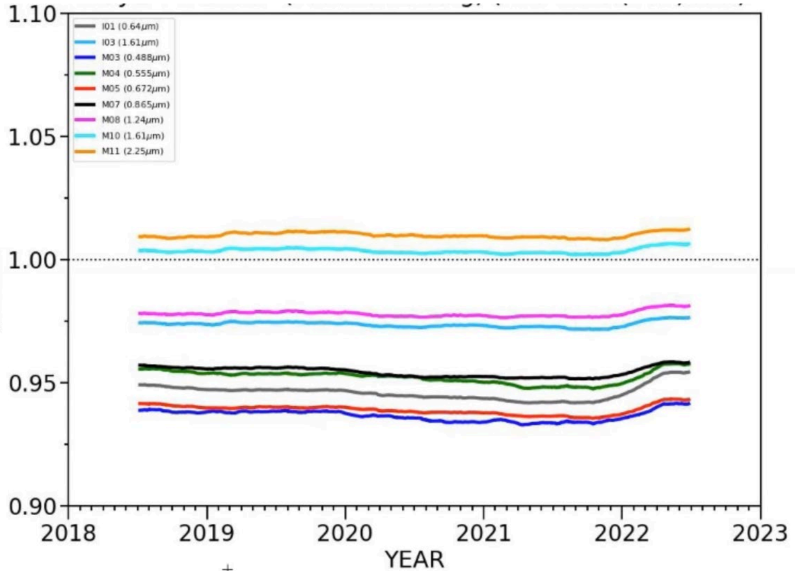
- NPP and N20 VIIRS I1 radiometric scaling factors are consistent within 0.3%
- Many studies indicate that the NPP is brighter than N20 VIIRS I1 by ~5%
- no SBAF was applied

NPP and N20 VIIRS RSB radiometric scaling

NPP-VIIRS observations normalized with the N20 BRDF$_{atm}$



N20-VIIRS observations normalized with the NPP BRDF$_{atm}$



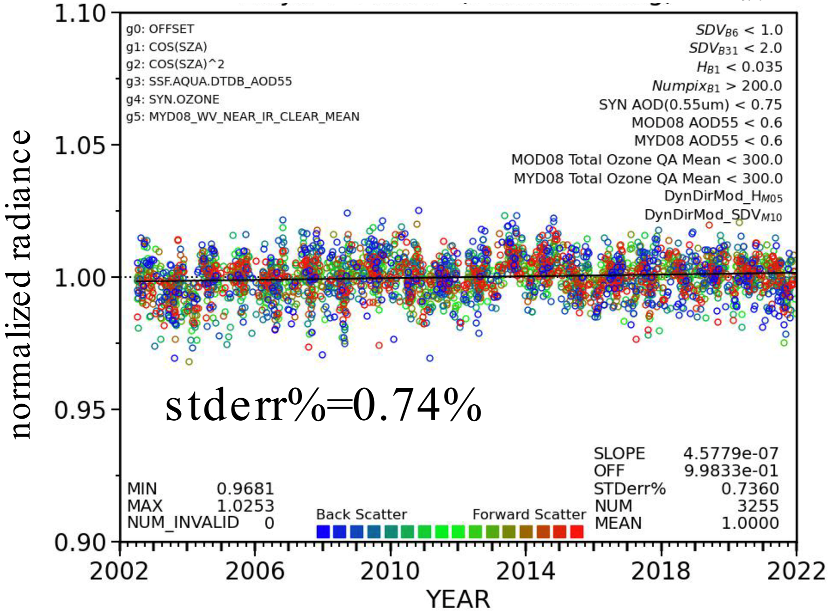
VIIRS band	NPP (N20 BRDF)	N20 (NPP BRDF)	NPPx N20
M3	1.0623	0.9374	-0.42%
M4	1.0458	0.9532	-0.31%
I1	1.0529	0.9472	-0.27%
M5	1.0625	0.9397	-0.16%
M7	1.0461	0.9550	-0.10%
M8	1.0213	0.9784	-0.08%
M10	0.9950	1.0039	-0.11%
I3	1.0255	0.9740	-0.12%
M11	0.9868	1.0102	-0.31%

- NPP and N20 VIIRS radiometric scaling factors are consistent within 0.4%
- M03 and M04 have inadequate AOD and O3 atmospheric corrections
- M11 may need a better PW atmospheric correction
- The Libya-4 natural variability may impact the difference

Comparison of the N20-VIIRS observations normalized with the NPP or N20 BRDFs

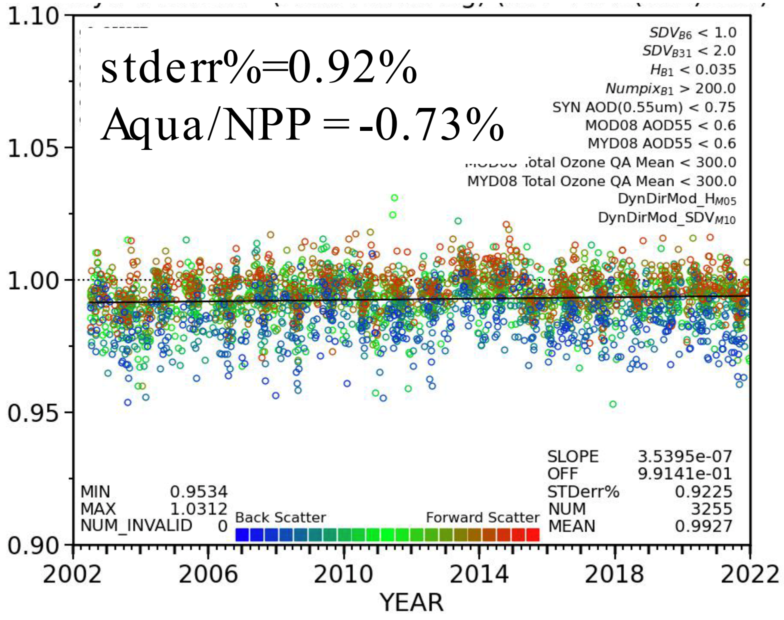
Aqua-MODIS observations normalized with the Aqua $BRDF_{atm}$

Aqua, B1 (0.65µm) (Aqua $BRDF_{atm}$)



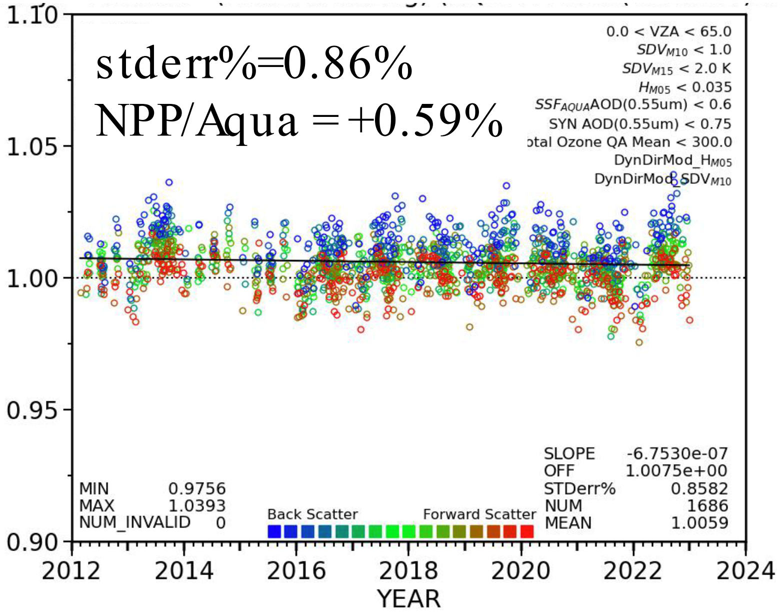
Aqua-MODIS observations normalized with the NPP $BRDF_{atm}$

Aqua, B1 (0.65µm) (NPP $BRDF_{atm}$)



NPP-VIIRS observations normalized with the Aqua $BRDF_{atm}$

NPP B1 (0.65µm) (Aqua $BRDF_{atm}$)



There are still some residual MODIS C7 response versus scan (RVS) calibration differences

Possible Libya-4 natural variability sources

Assumption: Libya-4 natural interannual variability is similar spectrally

Source	Impact	
Vegetation	Large shifting dunes do not support vegetation. 0.86µm band reflectance spike (months) not observed by other bands (maybe darker than underlying desert)	Manifested spectrally
Cloud cover	Increases reflectance in visible bands, decreased reflectance in SWIR bands	Manifested spectrally
Water vapor/Ozone absorption	Water vapor or ozone band reflectance not temporally in synch with other band reflectances	Manifested spectrally
Rain events	Very short lived (days), but could initiate vegetation greening	Too short
Aerosols/sandstorms	Short lived (days-weeks), impacts blue bands	Too short
Sand dune orientation	Similarly impacts all bands, slowly changes with the prevailing winds	Most Likely

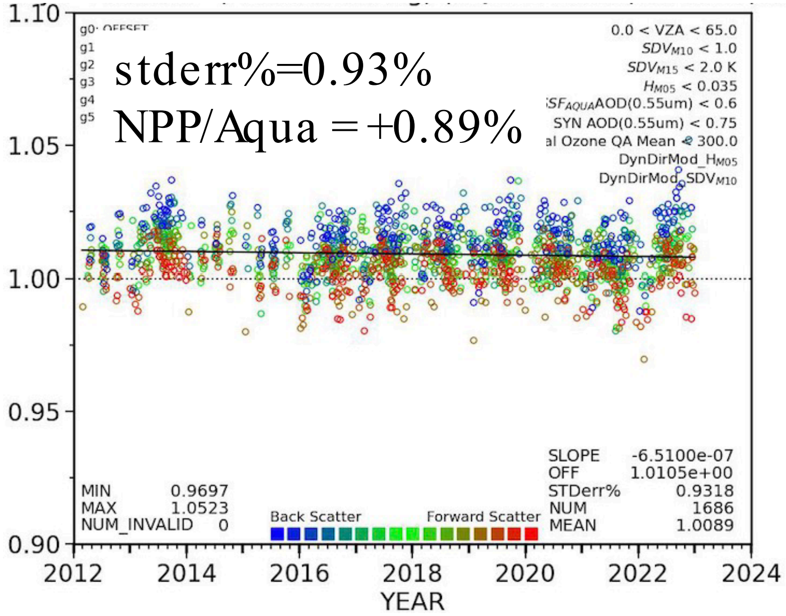
Conclusions

- The Libya-4 natural variability is similar across imagers and spectral bands
  - More than likely due to shifting prevailing winds changing the orientation of the sand dunes and shadowing
- Imagers in the same sun-synchronous orbit (mean local equator crossing times) can be radiometrically scaled referenced to the Libya-4 PICS
- The Libya-4 PICS radiometric scaling uncertainty can be reduced by better atmospheric corrections and removing the inter-annual natural variability

Backup Slides

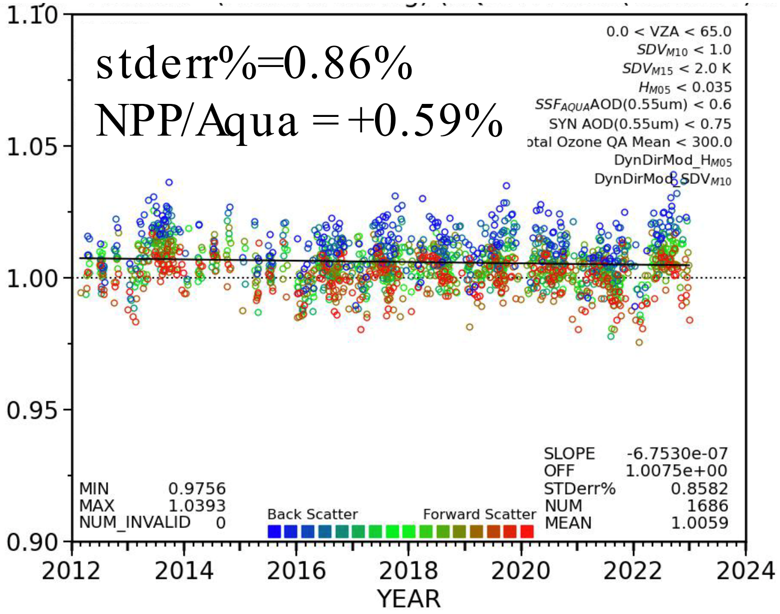
NPP-VIIRS observations normalized with the 5-year Aqua $BRDF_{atm}$

NPP B1 (0.65µm) (Aqua $BRDF_{atm}$)

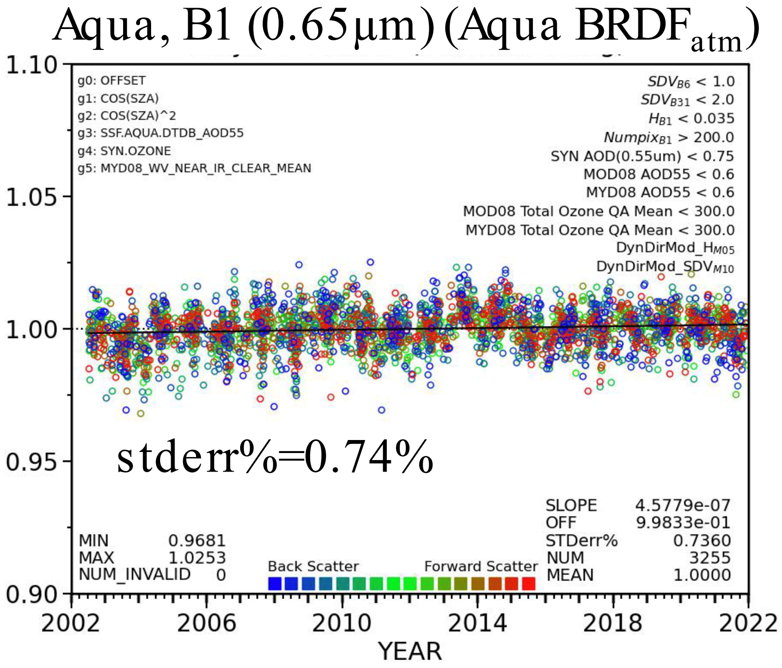


NPP-VIIRS observations normalized with the full record Aqua $BRDF_{atm}$

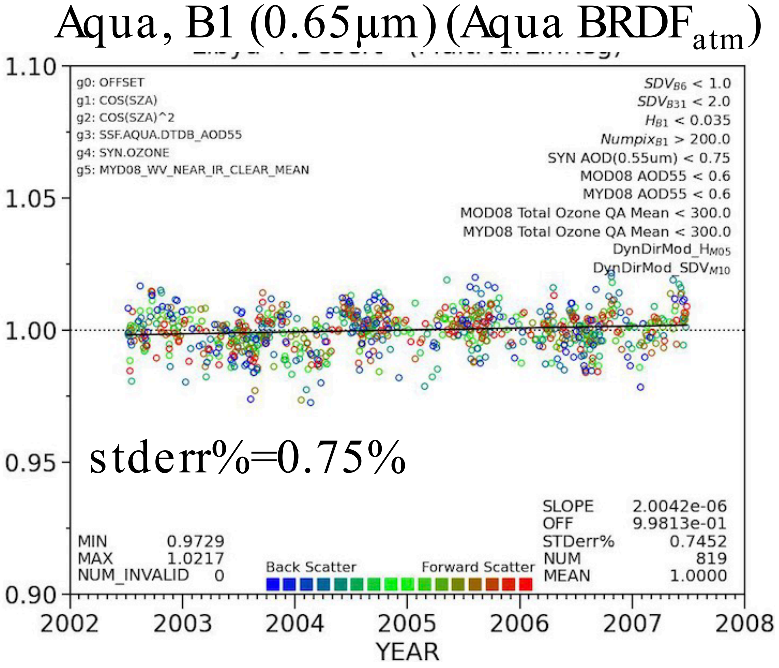
NPP B1 (0.65µm) (Aqua $BRDF_{atm}$)



Aqua-MODIS observations normalized with the full record Aqua $BRDF_{atm}$



Aqua-MODIS observations normalized with the 5-year Aqua $BRDF_{atm}$



Aqua-MODIS observations normalized with the 5-year Aqua $BRDF_{atm}$